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## Gravitational Wave follow-up with the PIRATE telescope

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## Abstract

The recent discovery of Gravitational Waves by the LIGO collaboration earlier this year has opened up a new window to astronomy, for the first time we are able to observe the universe using gravitational radiation instead of electromagnetic radiation. Our current research involves preparing our own robotic telescope (PIRATE) (Figure 1) to respond quickly to any alerts to such gravitational waves, and to follow these up with observations of the relevant search area in the sky. This poster will briefly outline the new setup of the PIRATE facility and summarise our current work on preparing PIRATE for the upcoming second LIGO observing run (O2).

## 1. Introduction

Thanks to a large investment by the Open University (OU) we have recently finished the construction of two new robotic observing facilities (PIRATE & COAST) located at the Observatorio del Teide in Tenerife. These twin facilities will be used by staff and students alike, for both research and teaching purposes. In addition to this the OU has acquired the Autonomous Robotic Telescope (formally known as the Bradford Robotic Telescope) that will continue to be used by the general public under the OpenScience Observatories program.

We are also signed up to the LIGO-Virgo EM follow-up group which gives us priority access to the first gravitational wave alerts. This will enable us to respond quickly to alerts and also help us to prepare the telescope for the future when the number of gravitational wave alerts increase significantly later in the decade. In addition to this the robotic nature of PIRATE gives it an excellent advantage when it comes to observing transient events that are time critical (such as short GRBs) and also longer period transient (such as supernovae) that require short but regular observations over a long duration. We intend to utilise this robotic aspect of PIRATE, to perform rapid photometric observations following an alert from the LIGO-Virgo Collaboration (LVC). Having missed out on any observing time during O1, we hope to take part fully in EM follow-up of alerts during O2.

## 2. PIRATE Facility

Previously PIRATE was located at the Observatorio Astronómico de Mallorca from 2008-2015 and while it was located there it was involved in collecting observational data for many projects such as monitoring exoplanet transits and the photometric follow-up of transients e.g.(Hay, et al., 2016) (Gómez Maqueo Chew, et al., 2013) (Lohr, et al., 2015) (Maxted, et al., 2014). In addition to this it was also used as a teaching telescope for undergraduate students to learn how to use and operate a telescope remotely over the internet. However last year the decision was made to relocate the telescope to Tenerife to benefit from the better observing conditions and improved facilities.

PIRATE itself consists of a 17-inch (0.43m) optical tube assembly (OTA) mounted on top of a 10Micron GM4000 HPS mount. Attached to the end of the OTA is a KAF-16803 CCD chip housed within a FLI ProLine PL16803 camera. This camera contains 4096 X 4086 pixels that provide a 43' field of view with a pixel scale of 0.63"/pixel (Kolb, 2014). In addition to this it is equipped with a 5 position filter wheel containing 3 broadband filters (Baader R, G, B) a H $\alpha$  filter and clear filter. The telescope is controlled by an automated observatory control software called ABOT that allows students and staff to control the telescope in real time over the internet as well as schedule observations into the observing programme. ABOT's other customers include: BlackGEM, Solaris and MeerLICHT (Sybilski, 2015).

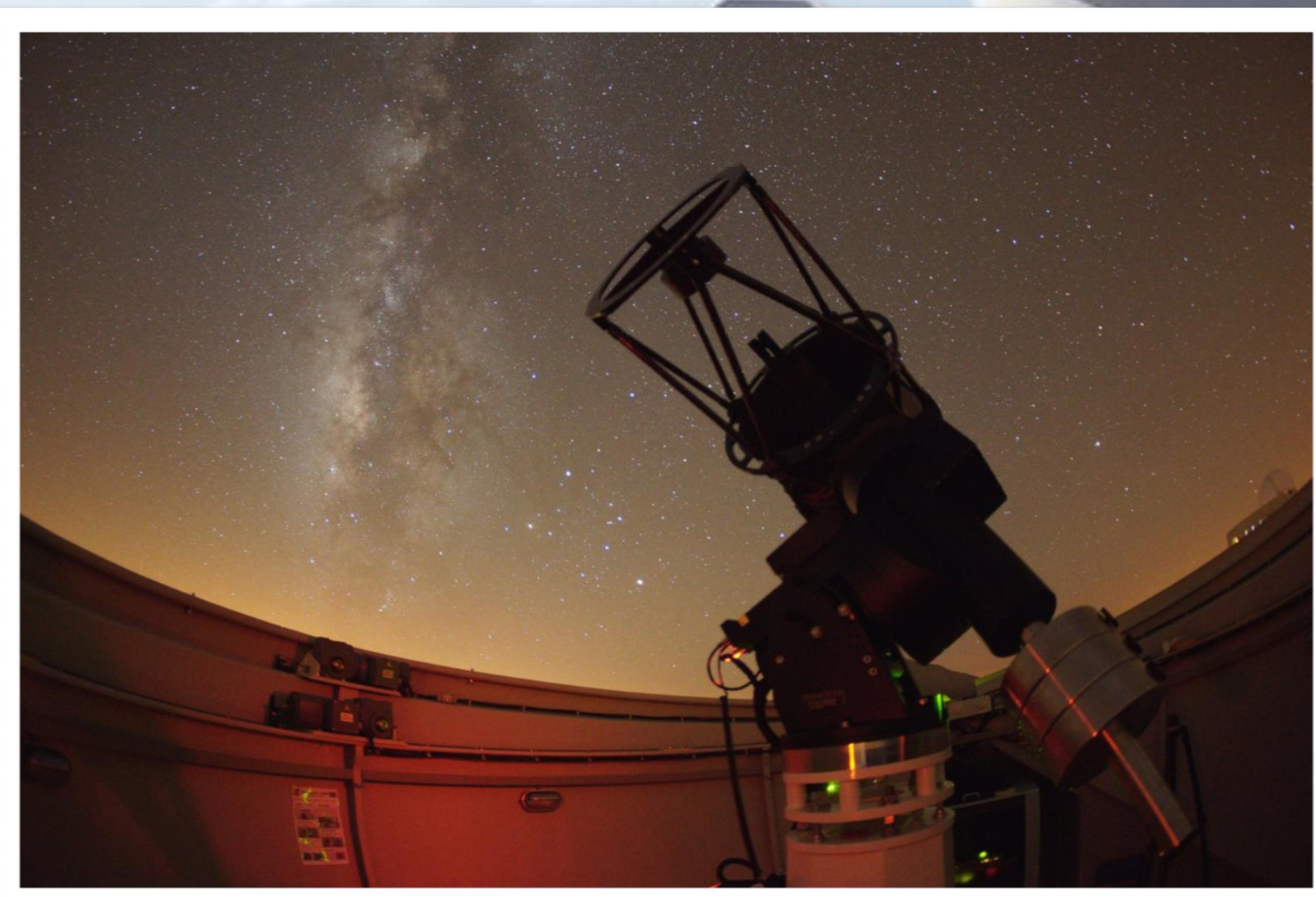


Figure 1. The PIRATE telescope at night under the Milky Way. Image Credit: Johannes Baader

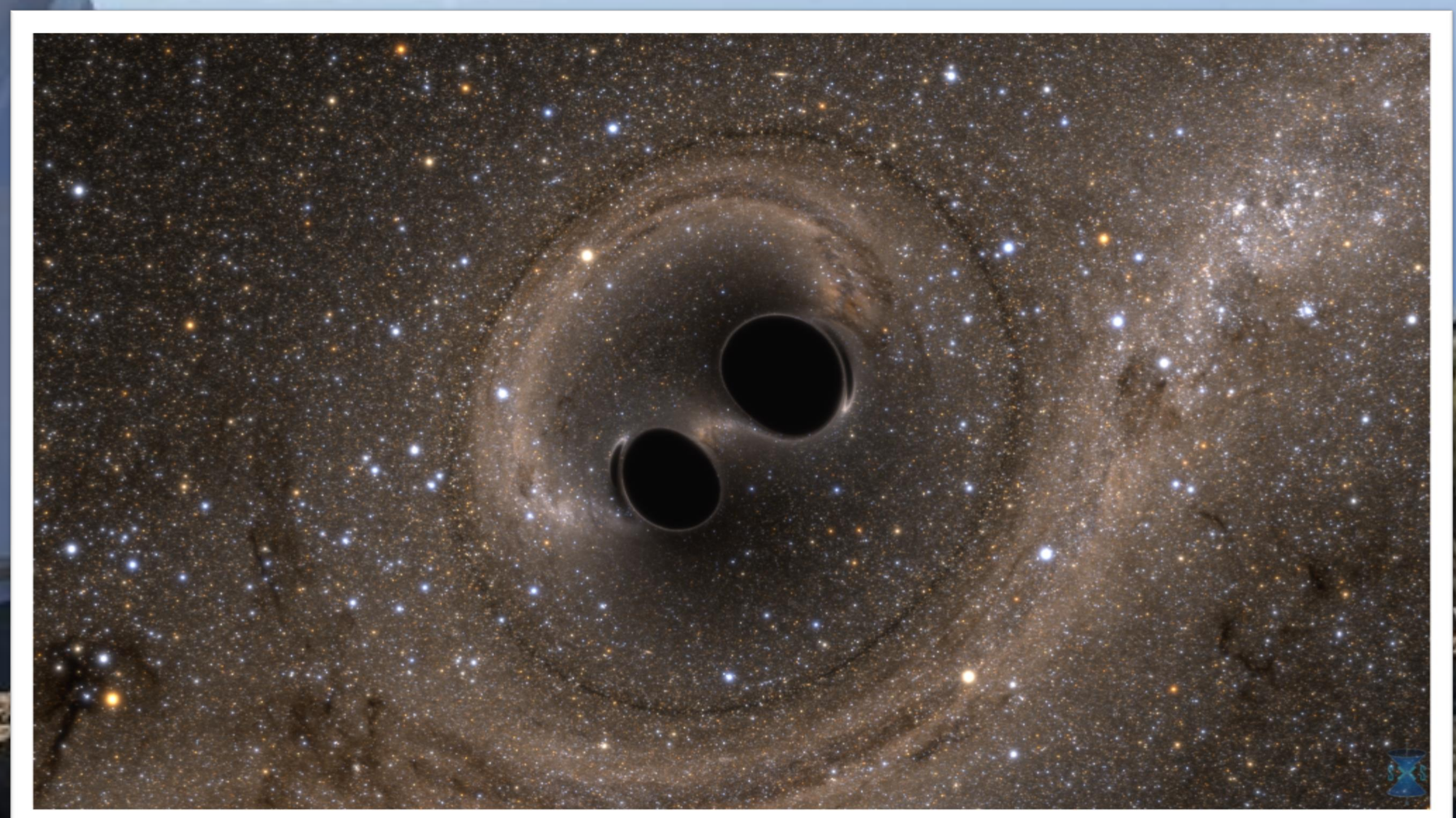


Figure 2. Simulation of the binary Black Hole merger detected by LIGO in 2015. Image Credit: Simulating Extreme Spacetimes

## 3. Gravitational wave follow-up work

To use PIRATE as a rapid response telescope it is important to remove all levels of human intervention and create a fully autonomous response to any alert the telescope receives. For LIGO-Virgo alerts this means not only programming the telescope to listen for and process alerts, but also determine a suitable observing target(s) within the large error box (see Figure 3).

So far we have been working on creating an automated pipeline to enable PIRATE to respond to Gravitational Wave triggers autonomously as soon as they are received. This has involved writing and modifying sections of code to programme the telescope to listen out for alerts over the GCN network and download a Skymap, as shown in Figure 3. The most important step in the process is allowing the code to select its own observing targets without any initial input from the observer. This involves narrowing down the search area to only the part of the sky observable that particular night; with a limiting airmass of two. Next the code makes use of catalogues such as the Gravitational Wave Galaxy Catalogue (White, Daw, & Dhillon, 2011) to target our observations at potential host-galaxies in order to reduce the search area further. In the future we hope to make use of the 3D Skymaps being introduced in O2 (Singer, et al., 2016) that allow for tighter constraints on these potential host-galaxies by taking into consideration the distance estimate produced by the gravitational wave search pipelines.

Due to the large nature of these Skymaps our efforts alone will not be enough so collaboration is key to this EM counterpart search, and as PIRATE is signed up to the LIGO GW follow-up community we aim to collaborate observations with other telescopes to enable us as a community to cover as much of the sky as possible across the entire electromagnetic spectrum. This has the potential to work extremely well providing all groups communicate effectively and employ similar rapid follow-up techniques to PIRATE.

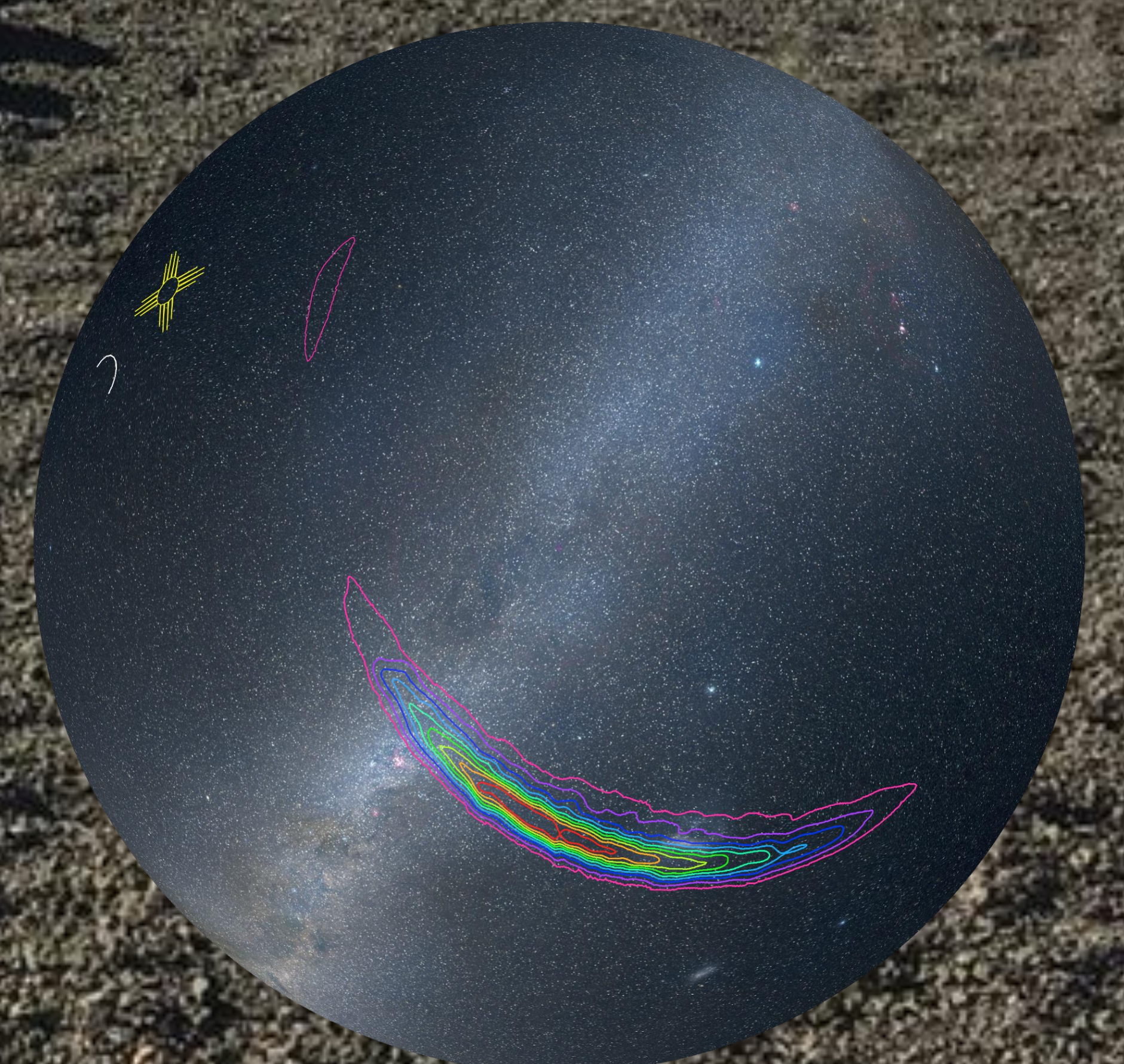


Figure 3. An example of the Skymaps produced for the LV-EM follow-up community. Image Credit: LIGO

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